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Digital Twins Miniaturized Simulation System of ICV based on MQTT and DDS

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Abstract

Under the development trend of "software defined vehicle", Service-Oriented Architecture (SOA) intelligent networked vehicle (ICV) control system is the development direction of vehicle enterprises. Aiming at low-cost, efficient and convenient verification of the function and performance of Intelligent Connected Vehicle System, this paper proposes a SOA-ICV digital twin system realized by Message Queuing Telemetry Transport (MQTT) and Data Distribution Service (DDS) communication protocol. The SOA-ICV digital twin system realizes the service of each functional unit of the miniature model system operation environment system and the simulation model vehicle intelligent system based on DDS; Based on MQTT, the miniature model system cloud platform, the miniature model system operation environment system and the simulation model vehicle intelligent system communicate with each other to form the smart city and intelligent transportation model to meet the requirements of verification and testing.

Keywords

Digital twins; Intelligent Connected Vehicle; Service-Oriented Architecture; Data Distribution Service; Message Queuing Telemetry Transport.

1. Introduction

In order to meet the construction needs of Intelligent Connected Vehicle (ICV), this paper carries out the construction of digital twin system for ICV, using micro-simulation to simulate the real vehicle with model intelligent vehicle and simulate the corresponding functions of the real vehicle[1]. The digital twin maps the state of the physical vehicle in real time. The micro-simulation simulation environment is used to help complete the relevant verification and testing work of smart connected vehicles. The test is quick, easy, can be repeated many times, good repeatability, high efficiency, low cost and better timeliness, which is a more realistic solution.

2. Car Cloud Relations

Building a cloud data platform for smart connected cars requires the organic combination of cloud computing technology and smart connected cars. Smart Internet-connected vehicles face different user needs, continuously evolving user experience, and the functional needs of intelligent vehicle perception and decision-making.

The digital twin micro-simulation system simulates intelligent cars and traffic scenes by using physical models and interfacing with the car cloud platform to realize online and offline collaboration, thus simulating various real scenes, virtual scenes and dangerous scenes, such as following cars, pedestrian crossing and avoiding static obstacles, etc., in order to test and verify the feasibility, reliability and stability of the interaction between physical cars and the car cloud platform [2-3].

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The ICV digital twin microsimulation system based on MQTT and DDS implemented in this paper is a complex composition involving multiple fields, which can be divided into microsimulation system cloud platform, microsimulation operation environment system and simulation model vehicle intelligent system. The micro model system cloud platform is the visual operation platform to collect the data uploaded from the simulation model car, control the micro simulation operation environment system and the simulation model car intelligent system; the micro simulation operation environment system can control the micro simulation urban traffic environment, involving light control module, garage management module, positioning module, etc.; the simulation model car intelligent system has the functions of vehicle condition perception, perimeter environment perception, multimedia service, etc. by carrying sensors. Multimedia services and other functions. The three components mainly interact through MQTT protocol to realize the effect of smart city and smart traffic. The system structure relationship is shown in Figure 1.

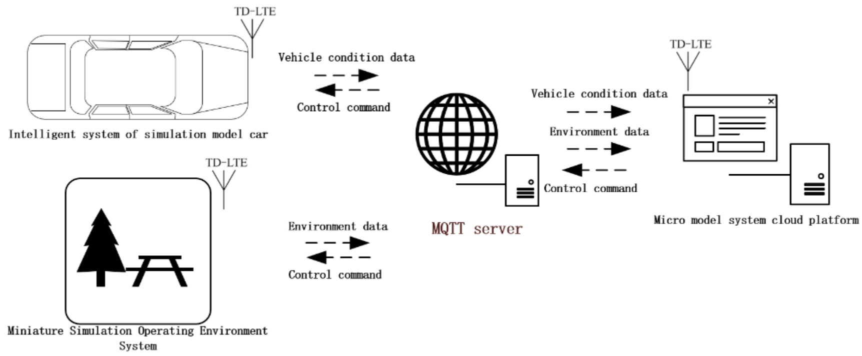

Figure 1. System Structure Diagram

3. Design and implementation of cloud platform for miniature model system

The micro-model system cloud platform is the control as well as coordination component of the whole simulation system. It can collect and display the status information of the microscopic simulation environment and simulation model vehicle in real time, enable remote control of the microscopic simulation environment and simulation model vehicle, extend the editing instruction set and view the historical instruction records. Coordinate the three parts of intelligent networked vehicle cloud platform, simulation model vehicle and microscopic simulation operation environment to ensure the normal operation of simulation model vehicle and microscopic simulation operation environment.

The miniature model system cloud platform can configure the vehicle-side services of the simulation model vehicle and send the configuration information to the simulation model vehicle for secondary loading and configuration through MQTT, which makes the vehicle-side services of the simulation model vehicle expandable and facilitates secondary development. This reduces the difficulty of configuring and secondary development of simulation model vehicle services, and enhances the ease of use and expandability of the DDS-ICV digital twin micro-simulation system.

The front-end is mainly used for page display and data visualization operations, and sends requests to the back-end by calling AJAX methods. The back-end SpringBoot framework adopts MVC development mode, integrating Mybatis-plus, Kafka, Dubbo and other frameworks, while the webSocket is used to enable the back-end to send messages directly to the front-end in order to display the messages received by the back-end to the front-end page in real time. It connects with MySQL relational database, reads and writes database by accepting front-end requests and returns the requests.

The microscopic model system cloud platform receives user target commands through the front-end visual UI interface, and the back-end gets the path from the car to the target location through the breadth-first algorithm [4]. The path data is sent to the car end through the MQTT protocol via command encapsulation, which plays the role of simulating GPS navigation.

MQTT data format conventions message format is divided into three categories: behavior message class, behavior return class and event message class. The Json type format is used to agree on the MQTT payload data format, as shown in Table 1.

Table. 1. MQTT data format convention table

Message type	Message field	Field Description	Ddata type
header	reqID	Requested ID	string
	serverKey	service name	string
	method	Method Name	string
	ackFlag	Answer ID	int
	encryptFlag	Encryption ID	int
	tuid	Device ID	string
data	params	Command parameters	Json
	result	Results returned	Json

After receiving the data of the simulation model vehicle control system and the miniature simulation operating environment control system through MQTT, the data will be forwarded to Kafka, and the back-end of the miniature simulation system cloud platform will receive and store the data into the cache through Kafka, and the front-end will send a request to the back-end to find the corresponding state information from the cache according to the name of the miniature model, return the information to the front-end and display it in the front-end UI interface.

4. Design and implementation of micro-simulation operation environment system

The miniature simulation operating environment system is to simulate the actual operating environment of the model car, so it consists of urban road traffic simulation sandbox and sandbox intelligent control system.

The miniature simulation operating environment system mainly completes the functional tasks such as intersection traffic light change, simulated pedestrian movement, obstacle placement, parking space detection, parking wireless charging, simulated ETC, simulated GPS positioning, etc. The control board adopts Jetson Nano, which has SD card or U disk reading and writing capability, with sufficient information storage capacity; it has 2GB to 4GB of memory, with sufficient program running capability; through Wifi or 4G wireless communication module, but has the Internet interaction capability, and the micro model system cloud platform for data upload and command reception.

4.1. System hardware design and implementation

The city road traffic simulation sand table effect is shown in Figure 2, the scene of all the relevant object sizes are presented in the real object ratio 1:10 size. There are two T-junctions, two straight roads, three groups of crosswalks, a parking lot, three groups of houses and buildings, etc.

Figure 2. Rendering of urban road traffic simulation sand table

The intelligent hardware integrated in the sandbox can be divided into four parts: light control system, UWB simulated GPS system, RFID-based ETC system, wireless charging management and parking space usage detection system.

(1) Light control system

The lights on the sandbox act as street lighting to provide sufficient light environment to eliminate the negative impact of the shadow of the surrounding environment on the visual processing of the simulation model car camera; room lighting in the building to enhance the visual sensory effect of the sandbox; three groups of traffic lights (traffic lights) to simulate the effect of real traffic lights to command and control traffic. The use of 1W LED beads to do each part of the light source, in the room that can provide sufficient illumination.

Due to the large number of LEDs and the large driving current required, and to complete the control of individual LEDs. Therefore, relay modules are used to control each group of lights.

(2) UWB-based simulated GPS positioning system

To implement a positioning system in the sandbox environment, GPS for outdoor environment will face problems such as large error and weak signal. Among indoor positioning technologies, UWB positioning technology has the advantages of high transmission rate, strong penetration ability and low cost. After Kalman filtering algorithm, its positioning accuracy can reach centimeter level, with error less than 20cm, which meets the demand of high precision positioning[5]. UWB positioning has lower resolution compared with RFID positioning, WLAN positioning, Bluetooth positioning and other indoor positioning technologies, which is more suitable for spacious indoor scenarios with some obstacles like sandbox type positioning requirements. Therefore, the UWB positioning system can be used to simulate the GPS positioning system in real outdoor environment.

(3) RFID-based ETC system

In order to achieve the management of the sandbox parking lot in and out of the vehicle, and simulate the real into the parking garage scene, and thus the sandbox designed the RFID-based ETC system. RFID has the advantages of fast information transmission, identification distance, etc., using radio frequency signals to achieve the non-contact information transfer[6]. When the vehicle enters the recognition range, the ETC system will extract, store and upload the vehicle information, and control the garage lever action. The garage needs to be separated in and out, and at least two ETC lanes are set up. Accordingly, ID cards capable of responding to the RFID module emission frequency need to be placed at the car end. Each ID card stores a different value and thus can do vehicle identification through the ID card. And the switching action of the garage lever is controlled by the limit servo.

(4) Wireless charging management and parking space usage detection system

Wireless charging technology is the key technology for electric vehicles, and there are mainly three kinds of electromagnetic induction type, magnetic field resonance, and radio wave. For

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this project with limited hardware space, the electromagnetic induction charging scheme is used, which can realize high-power long-distance wireless power supply wireless charging.

For the sandbox scene, there are not many parking spaces, the traditional infrared pair of tube induction type is used to detect the occupancy of parking spaces. Combined with the voltage comparator function role, when the infrared pair of tube sensor is blocked by the car, the module output low level, and vice versa output high level.

4.2. System software design and implementation

SOA service design can improve software execution efficiency, reduce the coupling relationship between services, and improve software reuse rate [7]. In the actual urban traffic environment, there are many intelligent control components. These intelligent units are introduced into the SOA architecture system to realize software-defined intelligent transportation, as shown in Figure 3.

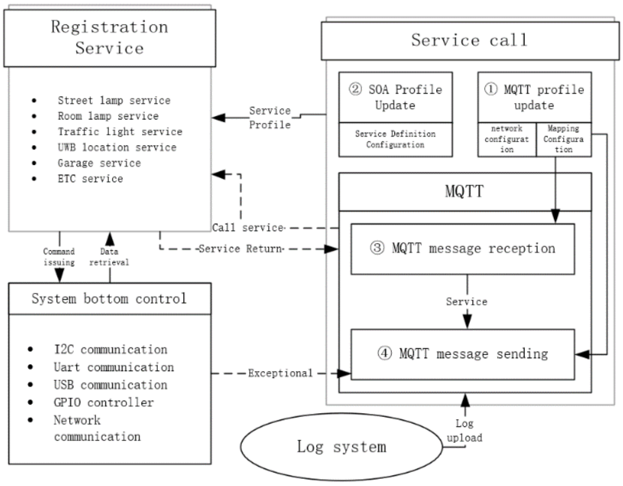

Figure 3. System architecture diagram of micro simulation operation environment

For each system module of the sandbox, develop the relevant atomic function DDS services(Figure 6).

(1) For the light control system, it is necessary to set and obtain separate switches for house lights, street lights, and traffic lights, and it is also necessary to set and obtain the time interval for alternating traffic light changes. DDS services are designed for each of the three types of lights.

(2) For the positioning system, the mapping relationship between UWB tag ID and simulation model vehicle device ID is established, and the UWB tag positioning information is obtained from the UWB base station serial port return data, and the tag positioning information is stored and managed by calling the service method.

(3) For ETC system, establish the mapping relationship between card ID and simulation model car device ID, obtain card ID reading information from RFID radio frequency card reading module, add and delete the garage vehicle list by calling the service method, and open and close the garage trolley to realize the monitoring and management of garage entry situation.

(4) For wireless charging management and parking space usage detection system, it is necessary to obtain parking space usage information from infrared sensor and modify the parking space status list by calling the service method. In order to save the use of power, the wireless charging module is only turned on after the car arrives at the parking space, and the switch can also be set by calling the service method.

The system functions of each part are realized separately by the DDS client. For each system part independent DDS client programming control is performed. That is, it is divided into 4 DDS clients for ETC processing, UWB processing, garage processing, and MQTT function processing.

Each client is combined with the current operation to mask some events or received commands. For example, when the micro-simulation cloud platform is artificially controlled to turn off or on the wireless charging module of a parking space, the parking space detection will not turn on the wireless charging module because there is a car parked in that space, or turn off the wireless charging module because there is no car parked.

5. Design and implementation of intelligent system for simulation model car

The overall design of the miniature model smart car frame is shown in Figure 4, which can be divided into communication unit, vehicle condition acquisition and environment sensing, and control execution as a whole.

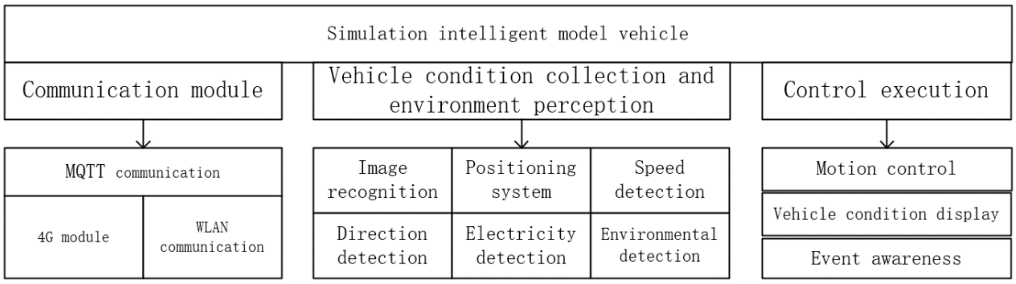

Figure 4. Overall design drawing of micro model intelligent vehicle

The speed information, position information, obstacles pedestrians and other environmental information of the car are collected by the speed sensor, UWB positioning module, laser distance measurement module, front view camera and surround view camera of the sensing unit. After collecting the information, the control unit makes motion decisions based on the current target instructions, generates control instructions, and sends them down to the execution unit. Based on the command information, the execution unit performs peripheral control operations such as motor control and voice announcement.

5.1. System hardware design and implementation

The system takes into account the number of peripherals, signal acquisition frequency, load performance and other requirements, the core controller needs to have high arithmetic power, sufficient memory and fast system main frequency. Therefore, the Jetson Nano B01 is used as the core controller and the STM32F411 chip is selected as the lower computer controller. The lower computer transmits the collected garage information to the upper computer through UART communication, and the upper computer transmits the control instructions to the lower computer for execution.

For the functions that the simulation model car should have, the modules are selected in combination with the reproduction space limitation.

(1) The worm gear motor has the advantages of smooth transmission, ultra-low noise, high torque, power-off self-locking, short transverse length, etc., and can be retrofitted with Hall encoder for vehicle speed acquisition.

(2) MPU9250 nine-axis sensor module, which can acquire three-axis acceleration, gyroscope, angle and magnetic field, can be used as a vehicle-end electronic compass as well as acceleration and angular velocity measuring instrument.

(3) TOF050F laser distance measurement module is used to obtain the distance of the left, right and rear objects of the car. It has the advantages of short measurement blind distance, high accuracy, millimeter-level measurement and low power consumption.

(4) The lithium battery voltage is detected by means of precision resistor divider followed by ADC acquisition as the vehicle battery power detection.

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(5) vehicle directional lights, lighting and other indicators, due to the uncertainty of the required brightness, the brightness of the LED can be adjusted by pulse width modulation (Pulse width modulation, PWM) signal, and thus can be used such as PCA9685 chip for sixteen PWM channel control, and its can be cascaded to expand the number of channels [8].

(6) 1080P distortion-free camera, which can reduce the work related to image correction and has enough high resolution to be used as front camera and surround view camera.

5.2. System software design and implementation

The exploration of SOA applications by Jonas Rox [9], Philipp Obergfell [10], and others led to the implementation of the software-defined vehicle autopilot solution promoted by SOA.

For the performance limitations of the vehicle system, the image recognition content related to the camera, such as pedestrian detection, lane line detection, obstacle recognition, traffic light recognition, etc., should adopt a lighter neural network model. As the development of YOLOv5 model, YOLOX model has a great improvement in network performance. The model is lighter and suitable for embedded systems.

The basic function of the vehicle is decomposed into four DDS functional services, namely, motion service, vehicle condition service, environment perception service and media service. Among them, the motion service is to control the simulation model vehicle motion related functions; vehicle condition service is responsible for collecting, monitoring and storing vehicle speed, acceleration, direction, door status, window status and other information functions. Environmental perception service is responsible for collecting, monitoring and storing environmental data information, such as laser ranging results and camera obstacles, pedestrians, lane line detection information; the media service is responsible for the voice synthesis broadcast task.

The acquisition time sequence of the camera module is different from that of the vehicle condition acquisition. The control logic of the vehicle side is completed by the coordination of three DDS clients, image monitoring, vehicle condition monitoring and MQTT function processing, as shown in Figure 5. In order to save performance waste and prevent inappropriate trigger actions, the car side shields some event triggers according to its own state. For example, the camera related detection action can be turned off when the car is stalled in the parking lot. When the car is in motion, the door opening and tail door opening instructions should be prohibited.

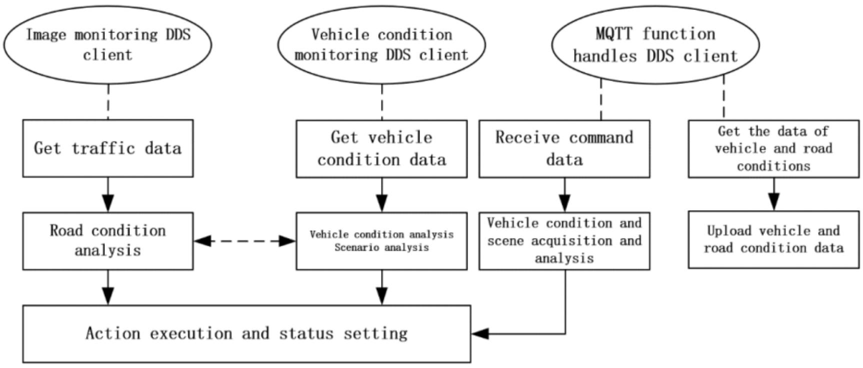

Figure 5. Working relationship diagram of image monitoring, vehicle condition monitoring and MQTT function processing DDS client

6. Conclusion

This paper designs an MQTT-based DDS-ICV digital twin microsimulation system, including three parts: micro model system cloud platform, micro simulation operation environment system and vehicle-side intelligence system. The data and commands are transmitted between the three systems via MQTT. The microscopic simulation operation environment system and the vehicle-side intelligent system adopt DDS communication protocol, and the system ontology doubles as a server and a client. The modules in the system are designed as atomized services, and the functional logic of the system is realized in the form of service calls by the client. The three parts of the system are interlinked to form a miniature analog digital twin system. The DDS-ICV digital twin microsimulation system designed in this paper greatly reduces the cost of verifying the functionality and performance of the SOA-architecture intelligent networked vehicle system, and improves the verification and development efficiency.

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